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ABSTRACT

Initial Apollo missions have the potential capacity to supply scientists with a plethora of new information even if lunar surface stay-time is limited to a matter of several hours. After conducting studies necessary to ensure success of the mission in progress and to enhance the probability of success of future missions, the astronaut's most valuable "scientific" occupation will consist of making relatively detailed studies of the lunar surface in the vicinity of the LEM, and, at the same time, collecting the proper samples for return to earth. Consideration of physical processes known to affect the lunar surface indicates that it is highly desirable that the astronauts have the capability of sampling at least the upper meter of the lunar surface.

It is essential that certain pieces of hardware be developed, including a camera, sampling tools and probes. It is also desirable that a portable radiation counter be included in the scientific payload for use in finding anomalous radioactivity and as a field tool used to distinguish different subsurface materials.

Safety considerations and severe limitations on the amount of available time, life-support, and mobility will probably limit the radius of astronaut operations to 1/2 km or less. These constraints, during initial missions, will not degrade the Apollo scientific mission since, at this time, it seems highly probable that the first manned lunar landings will be made in the midst of the most homogeneous, featureless marial plain which can be found. For that reason, the variety of accessible large scale ($\geq$1/2 km) geologic features is apt to be vanishingly small. It is expected, however, that marial surfaces will be rich with features of size several meters and less, such features having a relatively homogeneous spatial distribution and being readily accessible to Apollo astronauts both for observational and sampling purposes.

Numerous ideas and problems deserving future study have been noted and are recapitulated in the summary at the beginning of the memorandum.

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Subject: Initial Lunar Scientific Studies by Apollo Astronauts - Case 110

Date: March 4, 1964

From: N. W. Hinners
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TECHNICAL MEMORANDUM

SUMMARY AND TENTATIVE CONCLUSIONS

Initial Apollo missions, including a successful LEM landing on the moon's surface, have the potential capacity to supply scientists with a plethora of new information even if lunar surface stay-time is limited to a matter of several hours. The first order of business on the surface will be to conduct studies necessary to ensure success of the mission in progress and to enhance the probability of success of future missions. A preliminary analysis of some possible geologic modes of lunar investigation indicates that the astronaut's most valuable "scientific" occupation will consist of making relatively detailed studies of the lunar surface in the vicinity of the LEM, and, at the same time, collecting the proper samples for return to earth. Consideration of physical processes known to affect the lunar surface indicates that it is highly desirable that the astronauts have the capability of sampling at least the upper meter of the lunar surface. The acquisition of random grab samples should be discouraged except as an emergency procedure.

Safety considerations and severe limitations on the amount of available time, life-support, and mobility will probably limit the radius of astronaut operations to 1/2 km or less. Additionally, the astronaut on the surface may be required to operate only in the field of view of the LEM-based astronaut except in unavoidable blind spots such as directly beneath the LEM or when making a survey for LEM structural damage. These constraints, during initial missions, will not degrade the Apollo scientific mission since, at this time, it seems highly probable that the first manned lunar landings will be made in the midst of the most homogeneous, featureless marial plain which can be found. For that reason, the variety of accessible large scale ($\geq$1/2 km) geologic features is apt to be vanishingly small. It is expected, however, that marial surfaces will be rich with features of size several meters and less, such features having a relatively homogeneous spatial distribution and being readily accessible to Apollo astronauts both for observational and sampling purposes.

It is essential that certain pieces of hardware be developed, including a camera, sampling tools and probes. Those items will probably be required on every Apollo flight. It also seems desirable that a portable radiation counter be included in the scientific payload for use in finding anomalous radioactivity and as a field tool used to distinguish different subsurface materials which may appear surficially homogeneous on account of a dust cover or physical alteration by lunar-wide processes.

It is recommended that the astronauts be given the capability of making rapid preliminary analyses of lunar material. The purpose is two-fold: first, if the astronauts are able to collect more than 80 pounds of sample (present return payload capability), they have a means of selection and, secondly, even if the samples are lost before the nominal end of the mission, some compositional information about the lunar surface will have been obtained. A likely instrument for such analyses would be a rapid-scan x-ray diffractometer such as has been developed for Surveyor.

Numerous areas and problems needing future study have been noted. Those studies should lead to

(a) the determination of the desirability, from both engineering and scientific viewpoints, of utilizing the same landing area for several Apollo missions.

(b) further analysis of the desirability, feasibility, and best methods of preliminary sample analysis and selection by the astronauts prior to leaving the lunar surface.

(c) the determination of the kind of information needed in support of a roving vehicle mission.

(d) the determination of the most feasible way of extending surface correlations made at the landing sites and the best mode of investigation of large lunar features, e.g. by manned surface traverse, unmanned surface probes, or by manned or unmanned orbital reconnaissance.

(e) the determination of the type of information needed to certify that the moon would or would not prove to be a useful stable space platform for astrophysical observations.

(f) analysis of the desirability and feasibility of equipping LEM landing beacons with long-term, passive, lunar surface experiments which could be recovered by the astronauts.

(g) the analysis of the desirability and feasibility of rocket plume sampling during LEM touchdown.

(h) the development of a coordinated plan for all lunar science studies including formal presentation of the scientific objectives of lunar exploration.

(i) the integration of the lunar scientific exploration program with the overall Apollo mission plan. Without such interaction a sound and meaningful scientific program cannot possibly be developed.

INITIAL LUNAR SCIENTIFIC STUDIES BY APOLLO ASTRONAUTS

1.0 INTRODUCTION

We now tacitly assume that the Apollo manned lunar landings will be scientific missions rather than mere "political stunts". Previous to the landings, then, it will be necessary to carefully plan the scientific experiments in order that crew capability and available time be used to maximum advantage. Included under the general category of scientific experiments are certain 'engineering' experiments. The distinction is rather foggy, at best, since almost any information obtained in support of engineering requirements will at the same time constitute useful scientific data.

At all times it should be remembered that the scientific exploration of the moon will not be a one-shot affair and that information obtained from early flights will greatly influence later mission profiles. Additionally, note that many areas of discussion are incomplete and conclusions tentative. As new information becomes available about the moon and about the Apollo system, refinements and additions will be made.

This report is a first effort designed to:

(1) pose some of the scientific questions which arise concerning the moon,

(2) begin to delineate and analyze the scope of early Apollo manned lunar activity,

(3) assign rough priorities to those activities,

(4) indicate what may be learned from certain specific experiments,

(5) flag prospective problem areas and development needs, and

(6) serve as a basis for a more detailed scientific mission analysis.

2.0 SCIENTIFIC QUESTIONS ABOUT THE MOON

It is fitting, at this point, to note some of the questions which scientists pose about the moon. After all, our reason for journeying there is primarily to obtain information which will aid in answering these and related questions. By knowing beforehand what questions we desire to answer, the right tasks and experiments can be designed. The list which appears below is by no means complete - it is a product of the author's background and covers a range from the extremely general to the relatively specific, the latter often being an outgrowth of the former. The list suffices, however, to give the reader an insight into the scientific justification for manned lunar exploration and, later, to serve as a basis for judging some of the proposed lunar activities.

1. What is the relationship of the moon to the earth, i.e. did they once form a single planetary body?

2. What is the bulk composition of the moon? Is it chondritic, or even approximately so?

3. What is the surface composition of the moon?

4. Has lunar rock undergone any magmatic differentiation?

5. Does the moon possess a core, mantle, or crust?

6. Is the moon seismically active? Was it ever?

7. Do tektites come from the moon?

8. What is the relationship of the moon to meteorites?

9. Does the moon possess, however small, an atmosphere? Of what is it composed? Does the sun contribute to the lunar atmosphere?

10. Did the moon ever possess a hydrosphere?

11. What are the mechanics involved in supporting the lunar bulge?

12. Does the moon possess, however small, a magnetic field? Did it ever?

13. What are lunar rays, rills, ridges, mounds, etc.?

14. Are lunar craters of volcanic or impact origin?

15. What is the age of the moon and what are the absolute and relative ages of various lunar features?

16. What has been the cosmic-ray and solid particle flux on the lunar surface throughout its history?

17. What is the lunar heat flow?

18. Has there ever been a lunar biota?

3.0 CONSTRAINTS

In early Apollo missions, and in the absence of a lunar logistics system, the astronauts must carry all necessary scientific and engineering equipment in the LEM, which therefore limits that payload to about 215 pounds (Ref.1). It is expected that about 80 pounds of lunar sample may be returned to earth. The total time available for surface exploration will be limited on the high side by life-support constraints which at present may allow up to 24 man-hours. That is not continuous time, however, since the maximum capacity of the life support back-pack will be 4 hours (Ref.2). It seems likely that only one astronaut will be out of the LEM at a given time and that he may be required to remain in view of the astronaut remaining in the LEM. In addition to the limited life-support, low mobility and safety considerations will probably limit the radius of astronaut operation to 1/2 km or less from the LEM.

4.0 PROPOSED MANNED LUNAR ACTIVITIES - A PRELIMINARY EVALUATION

The general scope of manned lunar activities has been delineated in (1,3,4,5,6). In summary, and not necessarily in exact order of importance, they are:

(a) Measurements and observations necessary for the success of the mission in progress.

(b) Measurements and observations which will enhance the probability of success of future missions.

(c) Observation of natural lunar phenomena including geologic mapping.

(d) Sample collection.

(e) Emplacement of equipment requiring human dexterity or decision-making capacity.

(f) Astrophysical experiments using the moon as a stable space platform.

In formulating a plan for lunar experimentation, one cannot always rigidly restrict himself to any one of the above categories since some measurements and observations are germane to several. For example, determination of the depth of an incompetent soil layer has immediate consequences as regards astronaut mobility, design of future missions, equipment emplacement and geologic interpretation. It is, at once, an engineering and a scientific experiment. However, it is possible to evaluate the need for and return from certain activities and to assign a rough priority to them, always keeping in mind the constraints.

4.1 Measurements and Observations Necessary for the Success of the Mission in Progress

This activity takes priority over all others. For the first few missions, success of the mission in progress means the safe return of the astronauts to earth. There is absolutely no need to rush the scientific part of the mission at the risk of significantly increasing the probability of over-all mission failure.

In-LEM lunar-surface activities scheduled under this category will undoubtedly be detailed, as in (Ref. 8), and are not further dealt with here. After a successful landing operation, out-LEM activities should include:

(a) Continual testing of communications and life-support,

(b) tests of astronaut footing and mobility,

(c) observation of LEM attitude,

(d) survey for possible LEM structural damage,

(e) observation of the nature of any whisker or dust layer as regards interaction with the LEM and astronaut,

(f) monitoring of solid particle flux,

(g) monitoring of surface radiation (presumably equipment in the LEM and CM will be monitoring solar and galactic radiation)

Certain of these activities, such as (d-f) may need to be carried out only on the first landing if results are negative, e.g., if there is insignificant solid particle flux in the LEM landing area, it is probably insignificant in other lunar areas although the possibility of periodic increases must be kept in

mind. Items (e) and (f) will probably require special instrumentation in the form of solid particle and radiation detectors. In all likelihood, it would be desirable to return collected solid particles to earth for analysis which in turn might enable the determination of the particle source.

If proposed Surveyor micrometeorite experiments are successful and indicate insignificant solid particle flux, there may be a reduced need for further similar experiments. Irregardless of the outcome of a particular Surveyor experiment, which will probably be limited to one lunar day, and thus have low exposure (area x time), spent Surveyor or lunar roving vehicles represent long-term lunar environment experiments if they can be examined and/or retrieved. The possibility of inspecting a spent vehicle increases tremendously if a Surveyor or rover is used as a LEM guidance beacon. Whether or not specific, long-term passive, retrievable experiments should be designed for potential LEM beacons is a decision which deserves further study.

4.2 Measurements and Observations Which Will Enhance the Probability of Success of Future Missions

Second priority must be given to activities in this category. These can be divided into two classes, one pertaining to future LEM missions and the other to a roving vehicle mission (the possibility of a permanent lunar base is not considered here). For future LEM missions, analysis of the first landing, be it successful or unsuccessful, will be the prime source of information. If the LEM lands successfully, the astronauts should establish whether or not the landing would have been successful had the LEM landed in a nearby area. Ascertaining this depends on both visual observation and probing by a mobile astronaut.

Visual observation, with photographic back-up, would lead to an estimate of surface characteristics including variability of slopes, surface texture, fractures, etc. Probe measurements are needed to back up and amplify the visual observations. Specifically needed would be measurements of porosity, thickness, and strength of any "crust" and dust layers or pockets. Certain mechanical properties of "solid" rock, up to limits critical to Apollo, should also be determined. All of these measurements could probably be executed with a simple penetrometer device such as is currently used in the field by soils engineers although a study should soon be conducted to determine what specific information and instrumentation is needed in support of a roving vehicle mission. Any tracks made by the LEM landing gear should be investigated as should the area disturbed or acted upon by the retrorocket plume.

In the event that the landing site has been certified by a Surveyor roving vehicle, the astronaut measurements will serve to check the certification and enable increased confidence to be placed on information obtained by a rover at other sites.

Electrical conductivity measurements should be made on the surface material with an eye open to the possibility of obtaining information useful for the development of communications, and which would also allow better interpretation of lunar electromagnetic reflectivity and emission.

4.3 Observation of Natural Lunar Phenomena, Including Geologic Mapping

One of the eventual purposes of lunar investigation is to collect sufficient data to allow the reconstruction of lunar origin and evolution, both from a physical and chemical viewpoint. In turn, that reconstruction bears on the interpretation of earth and solar system history.

The analogous collection of terrestrial data has been a slow, tedious process. We are able to benefit greatly by terrestrial work, however, in that it indicates to us just which measurements and observations are apt to give the most valuable information per unit time and expense.

The prime surface-observing activity on earth has been that of geologic field investigation. In this activity the end result is usually a map portraying the areal distribution and structural features of the different rock types. Using the field data and information obtained from laboratory investigations of samples collected in the field, the geologist thence proceeds to reconstruct the geologic history of the area. The validity of the reconstruction is a function of the ability and experience of the geologist, the amount and type of data collected (this depends strongly on accessibility of the area and mobility of the geologist), the laboratory work, and the complexity of the local or regional geology. That the technique of good field investigation is both time consuming and intricate is amply demonstrated in references (3) and (6). The problem is compounded on the moon since there will be no previous surface study to tie into, mobility may be low and time will be short. In addition to those constraints, the following point should be noted. That is: the lunar surface is being continually exposed to "homogenizing" physical processes. Most important of the homogenizers are micrometeorite impact, sputtering, and radiation damage. If those processes have acted as we now believe them to have, many geologic features will be visually obscured. It may prove necessary to physically remove surficial material before adequate mapping can be accomplished.

It would seem that, in order to do minimally acceptable lunar field geology, at least one of the astronauts must be a highly competent geologist and have available a lunar stay-time measured in days or weeks rather than hours. The fact that lunar stay-time may be only hours does not, however, vitiate the necessity that the astronauts be competent geologists. Even if large area geologic mapping proves impossible on account of limited stay-time or mobility, geologic know-how will be essential for describing the surface as required in 4.1 and 4.2, for describing local (to the LEM) geologic features and for aiding in the selection of samples to be returned to earth.

That aspect of lunar geologic mapping which must be given a high priority consists of the correlation of lunar surface features with lunar photographic features. There has been sufficient terrestrial photogeologic work done to indicate that this would be a profitable activity. Once a correlation is established between photographs and surface, geologists are able to extrapolate with a fair degree of confidence.

At the present time, the lunar photographic features consist of relatively large geologic features such as craters, continents, maria, rays, rills, ridges, domes, etc. Undoubtedly, when better photographs become available depicting areas at greater resolution, smaller features will become evident and will need in situ identification. As the distance from the original site of identification and correlation increases, further checks are desirable. Those checks can be obtained in any of at least three ways: by having a relatively mobile astronaut do a reconnaissance survey over large areas, e.g. tens of miles from the LEM, by landing in photographically similar looking areas on succeeding flights, or by unmanned surface investigation.

Correlation should not be limited to lunar photographic features. Already there has been abundant analysis of the electromagnetic properties of the moon outside of the visible part of the spectrum and by the time of manned lunar landing there will undoubtedly exist much more detailed information, of high resolution, concerning lunar electromagnetic emission and reflection. In addition to gross subjective correlation, it will be necessary to observe the detailed fabric or structure of the surface in order to enable better interpretation of data on hand. More is said on this aspect of observation in sec. 4.41.

Since at this time it appears that the astronauts will not be able to rove far from the LEM and that stay-time will be short, the astronauts certainly will not utilize the full scientific potential of a given site. On the other hand,

if the number of Apollo landings is limited, as they will be, it may make more scientific sense to deliberately land in an area unlike the first. On that basis, the prospects for obtaining multiple surface checks for correlation purposes appear remote, at least for features which have low spatial density.

In all likelihood, however, the landing site selection for early flights will be dictated more by engineering requirements than by scientific sense with the following consequence: the astronauts will probably land in the most homogeneous, featureless, and geologically uninteresting area which can be found. This fact cannot be taken to mean that the site will be scientifically unrewarding. On the other hand, it does mean that initial investigations may be more concerned with activities other than mapping per se, particularly if the landing site is geologically monotonous on the scale of the circle of astronaut operation.

It might be informative at this point, particularly for the non-geologist, to broadly analyze some of those features which one might want to map and to evaluate the importance of classical-type mapping during lunar exploration.

The features which a geologist marks on a map depend on the rock type. Briefly, we now consider the three broad, basic rock divisions: sedimentary, igneous, and metamorphic.

Sedimentary rocks are those which have accumulated by settlement from water or air. In an environment composed of sedimentary rocks the geologist maps the areal distribution of the basic units, or formations, which are generally distinguished by specific rock type, e.g. sandstone, shale, limestone, etc. He notes the attitude (present "tilt" of the units, most of which were originally deposited nearly horizontal) and thickness of the unit, along with any structural features observed, directly on the map. Key to successful mapping in sedimentary rocks is good exposure and correlation.

If the rocks are not completely exposed, the usual case, the geologist must have some means of interpolating or extrapolating what he can see. This depends upon being able to correlate map units. Correlation is accomplished in many ways, any one of which may not be sufficient in itself but effectively in combination. Such criteria include: physical continuity, color, lithology, sequential occurrence, paleontology, etc. The establishment and usage of the criteria in a given locale takes considerable effort in all but the most geologically simple areas. Often correlation is made only after detailed laboratory work.

In gross, the finished map indicates the areal extent of deposition as a function of lithology and subsequent structural deformation. The detailed map is necessary if one desires to reconstruct the detailed history and environment of the sedimentary processes. The first Apollo astronauts, however, need not be concerned with such detail. The greatest implications would come from the mere existence of sedimentary rocks. This would mean that the moon at one time possessed an atmosphere and/or hydrosphere which in turn yields information concerning the internal evolution of the moon. For example, it would imply that the moon has been degassed, at least partially, and that it was tectonically active at some time in its history. The specific lithology of the sedimentary rock would also be extremely significant. Aside from gross properties of the lithology, earth investigation of returned samples would be most informative.

The moon is apt to possess a sediment unlike any terrestrial sediment - i.e. "moon dust". Any such "dust", whatever its origin, will lack size sorting such as is accomplished on earth by differential settlement in relatively viscous media (air or water) although there could be some gravitational segregation. Knowledge of the areal extent and variations in depth of any dust layer may be necessary for Apollo per se (see 4.1 and 4.2) and will be valuable in reconstructing and evaluating physical processes altering the lunar surface. Mapping of "dust" could turn out to constitute a large proportion of mapping in an otherwise dull, homogeneous marial plain.

Yet another lunar sediment could consist wholly of meteorite impact debris or ejecta. Presumably lunar rays, conspicuous around certain craters, are made up of such material. Scientists will want to know the composition of the ejecta, time of ejection, and the mass distribution as a function of distance from the impact. Such information will lead to answers to questions concerning the composition and energy of the impacting body, time scale of impacts, and the time scale of physical alteration of surface material.

Igneous rocks, those which have formed by crystallization from a melt, probably form the bulk of lunar rocks. If the igneous rocks are plutonic (those which crystallized at depth and which are generally coarse grained) the geologist could map the distribution of the various plutonic rock types (e.g. granite, granodiorite, gabbro) and their relationships to each other. Structural features in plutonic areas are often obscure or of such a nature as to require many measurements in order to make an interpretation. Should the rocks be extrusive or volcanic, such as basaltic lava flows, or ash flows, large area mapping

might indicate source area, number of flows, and time variation of composition.

A metamorphic rock is one which has undergone a recrystallization or mineralogical change in response to new physico-chemical conditions. In its simplest form the change is isochemical and reflects a change due only to changing (usually increasing) pressure and/or temperature. More often some chemical compound or element (e.g. H_2O, CO_2, Na, K, etc.) has been added or removed in addition to a P-T change.

Mapping lunar metamorphic rocks, should they exist, is bound to be at least as difficult as it is on earth. Aside from noting areal extent of the rock types encountered and structural features such as lineation, banding, faulting, etc., we would like to know whether the metamorphic rock was originally a sedimentary or an igneous rock. Sometimes this can be determined from the mineralogy and sometimes from field relationships, e.g. metamorphic rock grading into sedimentary rock.

There is no compelling reason to believe that only one of the rock types considered would be present although terrestrial-type sediments and metamorphic rocks are not anticipated. In the case that several types do exist, however, or that variations within a type exist, the geologist would be interested in determining the nature of the contact - is it a fault, depositional or igneous contact?

Chances are that a geologist - astronaut could spend all available surface mission time mapping or attempting to map. Based upon consideration of the mission constraints, the expected difficulties peculiar to the moon, and the fact that the first Apollo astronauts will probably not be experienced geologists, the conclusion is reached that geologic mapping, per se, will constitute but a minor portion of short duration Apollo missions.

The foregoing is not a condemnation of mapping on the lunar surface. The point is that detailed terrestrial-type geologic mapping would not be the most profitable activity during early Apollo missions. On the other hand, there will undoubtedly be a need for accurately locating (mapping) certain surface features for the sake of interpretation or in conjunction with sampling, even on a 4 hour mission. As an example of the former, suppose that the astronaut observes that certain craters are arranged non-randomly (say linearily) and that fractures or faults exist. Noting either on a map or, more likely, photographically, the distribution and orientation of the craters and fractures or faults would enable geologists to establish whether or not a positive correlation exists between the two structural features. Examples of the latter are given in section 4.4.

In several sections of this report it has been noted that the astronaut will be required to observe certain phenomena or objects. Most probably all observations will be accompanied by recorded vocal description. That description, however, will be time consuming and can never be complete. All visual observations should therefore be recorded photographically. A camera should be developed for such use, incorporating simplicity, versatility and ruggedness. Desirable features include light weight, a variable focal length lens, interchangeable film magazines, fool-proof film advance mechanism, and automatic exposure control with manual override.

4.4 Sample Collecting

4.40 General

It is the opinion of this writer that this activity will be the most singularly valuable scientific effort of early lunar exploration and should be given the appropriate consideration. The general process of sample collecting has been treated, heretofore, in an extremely naive manner. In view of the general ease with which collecting is done on earth this is understandable yet there are many important differences which alter the picture when considering lunar sampling. Some of these are:

(a) There is essentially no limit to the size sample which may be collected on earth. The total lunar sample cannot exceed 80 earth pounds for an unsupported mission.

(b) Geologists often return to sample localities to re-collect if it is found that they need more sample. This would be a highly wasteful action in lunar exploration.

(c) The terrestrial geologist can often leisurely survey a wide area and pick samples at convenient locations. The lunar geologist may be relatively immobile and will not have time for casual sampling.

(d) Earth sampling localities can be marked on pre-existing topographic or geologic maps and the sample oriented with respect to magnetic directions. There may be no suitable base map for lunar exploration (there is a good chance of having high-resolution photographs, however) and there may be no magnetic orientation potential.

(e) Biological and chemical contamination could be problems with lunar materials.

(f) Terrestrial sampling is usually done in both horizontal and vertical directions. On the moon, however, lack of terrestrial-type weathering and possible lack of tectonism may make it difficult to obtain vertical profiles.

(g) Physical and chemical alteration of the lunar surface is apt to result in a relatively homogeneous appearance of an originally heterogeneous surface, making it difficult to recognize and sample different rock types.

In the discussion of sampling which follows, it is assumed that an astronaut will be able to descend from the landed LEM to the lunar surface and thence proceed with his tasks. It is possible, however, that the mission may be aborted during touch-down or before an astronaut has been able to descend to the surface. In the case of the former it might be desirable, and is evidently possible, to obtain a crude sample of the lunar surface by sampling the rocket plume (personal communication from Don Beattie, NASA-OMSF-MGL, December, 1963). In the latter situation a mode of remote sampling from the LEM would be needed. Both aspects of emergency sampling deserve further thought, particularly as regards the feasibility of adding another operation during the critical descent phase, although it might be made completely automatic, and as to the value of a sample which has been blasted loose from the lunar surface by hot rocket-exhaust gases.

Although the amount of sample returned to earth may be limited to 80 pounds, it is possible that the astronauts will be able to collect much more than that. Obviously, then, some sort of selection criteria are needed to enable the astronauts to choose the most interesting samples and/or to weed out unnecessary duplicates. It is not immediately obvious, however, that such selection will be an easy matter, particularly if the surface rocks are fine-grained, glassy, or highly altered. The selection technique must provide rapid analyses - preferably a matter of minutes - and require only simple sample preparation. That would indicate an instrumental analysis, probably for mineralogical or elemental content. As a preliminary judgment, the former seems best. A rapid mineralogical analysis could be done by the rapid-scan x-ray diffractometer developed for Surveyor. That raw data could be roughly analyzed in situ and also telemetered to earth for permanent record and for a refined analysis. (It seems likely that by the time of Apollo flights a large catalogue of x-ray data will be stored on magnetic tape, enabling rapid automatic analysis). An added inducement for carrying out a preliminary analysis, via earth-link, is that in the event of sample loss during the return flight the samples have already yielded valuable scientific information, i.e. all is not lost. The whole question of in situ analyses deserves further study.

A prerequisite to intelligent surface sampling involves knowing the specific analyses which a given sample will undergo. In turn this leads to certain requirements regarding sample size, field location, orientation, and handling. The taking of random grab samples would be of limited value and is to be discouraged except under emergency conditions such that no other sampling effort is possible.

To know beforehand the specific analyses which one would perform on lunar samples implies a knowledge of the physical and chemical characteristics of the sample. Since this is obviously not possible, at least for the first mission, we must set up a broad model which embraces the possible variations and which enables us to be prepared for all eventualities. For the model there will then be a list of required experiments and observations.

4.41 A Geologic Lunar Surface Model

For the purposes of this section, consider the lunar horizontal surface profile as being composed of an array of vertical surface profiles. The vertical profiles can then be dissected into possible component layers, a layer being defined by unique physical or chemical properties such that the layer requires handling and analysis in a manner different from that of another layer. Any of the layers which may be found on the moon have been built up from some smaller unit(s).of matter. The original manner in which a layer was constructed is often reflected in the present fabric. Indeed, the very a priori division into layers and the nomenclature of the layers connotes that something is known about possible lunar processes and resulting texture of materials formed.

Layer A. Chemical. It is conceivable that the surface of the moon will be covered, wholly or in part, by a coating of chemical sublimate(Ref. 9). This layer could take the form of whisker crystals. A whisker layer would probably, though not necessarily, be thin (microns to centimeters) since it would tend to be destroyed by micrometeorite erosion and it is not clear where new source material would come from once the lunar surface is covered to a shallow depth.

A chemical layer consisting predominantly of whisker crystals would probably have a very delicate fabric made up of a network of crystals or a mat with protruding individual crystals. Unless a method is developed such that the network can be impregnated in situ, the fabric would probably be disturbed or destroyed upon handling (it is possible that impregnating would also disturb the fabric). If the dimensions of the whisker layer are large enough to be observable by the unaided

eye (on the order of mm.) the astronaut can describe the structure and from then on not worry excessively about preserving it since knowledge of the minute detail of the structure, though highly desirable, would probably not be necessary for the determination of origin. The thickness of a whisker layer should be determined in situ since that can, in conjunction with other information, lead to estimates of the time constants involved in creating or destroying such layers.

A thick (> cm) whisker layer or thin whisker layer over a dust layer could possibly be sampled by use of a cookie-cutter type apparatus which would core a sample. If the layer is too thin to core (< cm), the astronaut might be forced to simply scoop or scrape the layer off the substrate.

It is possible that a chemical layer might consist of sublimate or whisker crystals of such a small scale that it would be unobservable by the unaided eye or even under medium power magnification. For this possibility, and in any case, provision should be made to sample an extremely thin surface layer. An easy way to do this would be to press a piece of adhesive material onto the surface, peel it off, and pack it away.

The mere existence of a whisker layer will not in itself indicate whether the material originated as a volcanic sublimate or as impact-vaporization sublimate unless typical identifying features,such as volcanic vents or fumaroles,are present and correlated with the occurrences.

Layer B. Crust. A crust formed from pure sublimate or from dust cemented by sublimate might be thin or thick depending upon the nature of disruptive forces and supply of sublimate and dust. It would be apt to have considerable strength and require some sort of coring device for sampling. In situ observation of a crust should note the strength, thickness, porosity, layering, color, grain size, and areal extent. Efforts should be made to collect a sample in as undisturbed a state as possible. This suggests that the astronauts use a coring device with a contained sampling chamber.

As was the case with a whisker layer, the existence of a crust per se will not indicate how it was formed unless it can be correlated with other identifying features although other analyses, such as chemical, may well settle that question. A laboratory study of grain-cement relationships would be invaluable in helping to determine the history of a crust layer.

Layer C. "Dust". It is possible that the lunar surface contains significant "dust", such dust consisting of small pieces of solid particulate matter. The thickness, cohesiveness,

porosity, etc., of a dust layer could vary over wide ranges. If the dust has undergone compaction it might resemble certain terrestrial sediments such as loess. A dust layer can be treated in a manner analogous to a crust as far as visual observations and handling are concerned. In addition to areal extent, the depth and porosity-depth relationships of such a layer are critical to the interpretation of lunar history. A seismic probe might be needed to determine the depth if that depth is beyond the capability of a simple penetrometer or shallow coring device.

Layer D. Primary Rock. This layer would consist essentially of solid rock, solid in the sense that it is a relatively dense aggregate of mineral crystals (or possibly glass) which has not been subject to secondary physical or chemical alteration since it was formed. Terrestrial type sediments are included in this category.

Layer E. Breccia. Technically this is a rock consisting predominantly of coarse angular fragments. Such a rock could be produced on the moon by meteorite impact, volcanic activity or fault action. It might be relatively loose and friable or it might be cemented into a hard aggregate. It is probable that meteorite ejecta would fall in this classification.

A breccia layer could consist of a wide range of fragment sizes - from meters to microns. On earth there are often two or more size groupings, e.g. large blocks cemented by or included in fine-grained material. It would be important to note those relationships and to sample the complete material, i.e. not to pick out a large fragment and leave behind the matrix. Breccias are not necessarily "loose" - they are often, particularly volcanic breccias, completely indurated or welded and as hard a rock as can be found. The thickness and areal distribution of a breccia layer would be clues to its origin. Fault breccias are often found in long, narrow zones (feet to 1000's of feet wide and feet to miles in length) while impact breccias, including ejecta blankets and rays, would be apt to cover large, broad areas. Volcanic or igneous breccias can also cover large areas. The type of breccia would be readily distinguished on the basis of characteristics other than its thickness and distribution if those properties were unobservable.

One cannot predict the combination of layers which will be found in a lunar surface profile although it is possible to generalize and say that, in the simplest case, layers A, B and C would probably overlay D or E and that E would usually overlay D. Complex interlayering is possible and most likely probable.

4.42 Depth of Vertical Sampling

Ideally one would like to sample to a depth such that no new information would be gained by proceeding further. In practice this point is never reached since there is continuous variation in bulk properties and/or environment of the rock or soil. Additionally, there comes a point where the effort per bit of new information is extravagent or even technically impossible.

The other extreme consists of merely scooping or picking up surface samples. Somewhere in between is the optimum but this optimum cannot be predicted a priori. It is possible, however, to determine a minimum desirable depth based upon certain known physical effects to which the lunar surface is constantly exposed.

There are several physical processes which are actively altering the surface material of the moon. Some of these, such as micrometeorite and meteorite impact, thermal cycling, and cosmic ray bombardment, can be crudely evaluated as regards their effect as a function of depth.

It has been estimated by Öpik (Ref. 10) that the mass of micrometeorite-eroded dust will not exceed a layer equivalent to 20 to 100 cm. He also believes that the actual accumulation of micrometeorite dust might form a 20-40 cm layer if it were evenly distributed over the lunar surface. The accumulation in pockets could be greater.

The moon's surface is alternately heated and cooled as it goes through successive lunations. During this period the surface temperature varies from less than 120° to about 400° K. This temperature variation may or may not be effective in altering physical and/or chemical properties of the surface material. It is not accurately known to what depth thermal fluctuations occur although it would seem that a relatively constant temperature might be reached at depths of the order of 50 cm (97% attenuation for a synodic harmonic heat wave of $\lambda = 14.5$ cm) and that the temperature at that depth is about 212°K (Ref. 11).

The lunar surface is, and undoubtedly has been, exposed to cosmic ray bombardment. An estimate of the depth of cosmic ray effects can be obtained by two independent methods. If the cosmic ray flux as a function of energy, the chemical composition of the irradiated material, and the appropriate nuclear constants are known, the penetration depth can be calculated. The other method, that which is usually used, consists of looking at the depth effect in meteorites which have been exposed to a

bombardment similar to that expected to have occurred on the lunar surface or by observing the effects of accelerator radiation on targets approximating meteorite composition. The mean free path thus found for absorption of cosmic-ray nucleons and π mesons is about 150 g/cm^2 (Ref. 12). Therefore, for a silicate rock of density = 3 g/cc, the mean free path is about 50 cm. In such a rock, the cosmic-ray effect would be diminished by 86% at 1 meter depth. For a dust layer of ρ = 1 g/cc one would have to sample to 3 meters to obtain a corresponding decrease. The attenuation at the base of such a 1 meter dust sample would be about 51%.

From the preceding it is obvious that the astronauts should have the capability of sampling both rock and dust to depths of at least 1 meter if meaningful evaluations of depth effects are to be carried out on the returned samples. Eventually, when logistics and time warrant, sampling capability should be extended to depths of at least 5-10 meters.

A naturally exposed lunar vertical profile (cliffs, pits, etc.) might suffice for certain experiments, such as observing and sampling the rock or soil type, but it would not, in general, provide proper samples for observing depth effects which vary as a function of the exposure geometry. The obvious solution is to create a new vertical profile either by drilling (preferably also coring) or by blasting. The former method is probably preferable but it is doubtful whether or not a drilling rig and power supply could be carried on an unsupported mission on account of the weight needed - about 250 pounds (Ref. 4). Lastly, it is possible, if the surface material is relatively soft, that the LEM will create skid tracks of appreciable depth in which case part of the vertical profile will be exposed to view.

The feasibility of blasting, via shaped charges, has not been established either as a practical way of sampling or from safety considerations. Further study of proposed sampling tools is needed both from an engineering and from a practical viewpoint.

4.43 Horizontal Sampling

On account of restrictions on the depth of sampling as performed by an astronaut, it may not be possible to sample the complete vertical profile at a given point. If the layers have variable thicknesses, e.g. dust pockets, it might be possible to get equivalent information by moving to a new sampling location. Even if the vertical profiles are apparently homogeneous in structure, it would be desirable to sample many different points in order to determine the variability of other

properties. For example, should water exist on the lunar surface it would tend to accumulate as ice in areas which are permanently shaded (Ref. 13). Since very little permanent shade exists in lunar equatorial regions, where the LEM will probably land, the astronauts should be taught how or where to locate likely water sites, presumably through the use of high resolution photographs if such exist.

The exact number of sampling localities cannot be categorically stated at this time. It will eventually depend upon the facility with which vertical sampling can be accomplished. If vertical sampling proves easy, the number of sampling locations will be limited by time and return payload available and the observable surface variability. For instance, if the surface appears extremely heterogeneous, and after obtaining several vertical sections, it would make more sense to take many shallow samples rather than use time obtaining more vertical sections. If vertical sampling is difficult, then it would be in order to decrease the depth of sampling and to increase the number of sampling locations.

4.44 Terrestrial analyses

As noted in 4.40, we must know what kinds of analyses the returned samples will undergo in order to be able to determine methods of sampling. In turn, this leads to further questions such as priority of analyses with respect to one another.

Once a given experiment is suggested, the following must be determined, for self-evident reasons:

(a) What scientific knowledge will be gained by performing the experiment?

(b) Is that knowledge general or is it unique to a particular sample?

(c) How much sample is needed?

(d) Is the value of the sample reduced by contamination of any sort?

(e) Is the analytical method destructive for the particular experiment or can the same sample be used to repeat that experiment?

(f) Is the analytical method destructive for <u>any</u> further experiments or can some other analysis be performed on the same sample?

(g) is there need for analysis immediately upon return of the sample or is it of no consequence if the sample sits for several days or weeks or even months before the particular analysis?

(h) Does it make any difference from where on the moon the sample comes?

(i) Is it necessary to know accurately from where the sample has come?

(j) Is special handling required in obtaining, packing, and transporting the specimen?

(k) Is it necessary to know whether or not the sample is indigenous to the moon?

Certain of the questions posed at the beginning of this section (a, g, h) are so general that it is worth discussing them without reference to particular experiments and others, such as (c) require detailed study beyond the scope of the present report.

Aside from the fact that certain individual experiments must be conducted soon after sample return for scientific reasons (such as decay of very short-lived radioactive elements), a case can be made for doing all experiments before the next flight. Only in this way will best use by made of the astronauts' time. For instance, if it is found that lunar samples have traces of life, increased sampling specifically for biological purposes might be in order. If no signs are found, that sampling would become subsidiary relative to some other type. Early analyses might indicate that sampling procedures need revision and, more important, may turn up unexpected results which would bear directly on following missions.

The question of the original source of the sample is critical to any interpretation of analytical results. It is quite obvious that samples of meteorite material lying on the lunar surface will not significantly aid in furthering the interpretation of the history of the moon, per se, but could be used in the studies on cosmic-ray bombardment and meteoritic influx studies. What is needed, then, is a method or set of criteria which will allow the distinction of meteoritic vs lunar material. If the lunar surface composition is similar to that of chondritic meteorites, it might be difficult to determine whether or not loose material is lunar or meteoritic but it should be relatively easy to spot material which is definitely lunar by its structural and petrological relationships.

A short listing of proposed laboratory investigations of lunar material has been presented by Anders (Ref. 7) and includes a brief, optimistic description of what may be learned from the analyses under ideal conditions. Using that list as a base, we shall here enter into more detail, all-the-while attempting to answer some of the questions put forth earlier.

AGE DETERMINATIONS

The technique of radiometric age dating is well established. The most reliable techniques involve the use of $Rb^{87} - Sr^{87}$, $Pb^{207} - Pb^{206}$, U, Th - He^{4} and $K^{40} - Ar^{40}$. It is generally easy to obtain a date for a sample but deciding how good that date is and what it means is often another story. The usual ploy is to date a sample by at least two independent techniques. The agreement or disagreement between the results may then be an indicator of the history of the sample and/or the reliability of the age determination.

Consider that a volcanic rock has been returned from the moon and that it has a certain age. That age per se will tell us when that rock (or some mineral in it) became a closed system for the particular elements used in the determination. If the age was determined by the K-Ar method, it ideally tells us that x years ago that rock cooled to a temperature such that argon no longer escaped from the system. For extrusive volcanic rocks that time is usually close to the time of extrusion. If argon has been continually leaking out of the rock, the age will be a minimum. If the age can be established as being accurate, it will tell us that the moon was hot enough at some depth to melt rock at that time. A single lunar age date would have particular significance if it were either very young ($\approx 10^{6-7}$y) or very old ($\approx 4 \times 10^{9}$y). The former would indicate that the moon was hot recently, while the latter would indicate that at least parts of the moon have remained relatively unaltered for a long time - a time longer than that yet found for any terrestrial rock.

The cosmic ray dating method has the potential(see p.23)of being valuable in determining the relative and absolute ages of impact or volcanic craters. This conclusion is based upon the premise that parts of the crater proper or the debris thrown out to form ejecta blankets or rays contains a large portion of lunar material which was not exposed to cosmic rays previous to the impact or volcanism. An exposure age determined for such material will then be the age of the crater. In the case of ejection material it must be assumed that a correlation can be established between the debris and a particular crater and that the debris did not have a previous exposure history.

The assumptions can be checked by dating several pieces of debris which appear to come from the same impact or volcanic event.

If terrestrial analogy is valid, it will be necessary to date many samples from many localities before a congruent picture of lunar evolution and processes will emerge. It will be absolutely necessary to know the geologic environment of the samples in order to obtain a comprehensive picture.

COSMIC RAY EXPOSURE HISTORY

If a segment of lunar surface has been exposed to a constant cosmic ray flux and has not been physically or chemically disturbed, analysis of the stable and radioactive elements produced by the rays enables the determination of the exposure time and thus the age. If the standard radioactive dates are available, on the other hand, an opportunity is provided to check the assumption of a constant cosmic ray flux through time.

If the surface of the moon is being eroded, the analysis may give an indication of erosion rate, particularly if erosion and catchment areas are both examined.

The real situation may be quite complicated and not immediately lead to clear cut answers as to rates of erosion, etc. A constant mixing of surface material, physically by impact and by addition of meteorite material exposed to cosmic rays before becoming part of the lunar system, could result in a very confusing situation. If surface particles are very fine grained and subject to thermal cycling it is possible that many of the cosmic ray produced nuclides would escape (e.g. He, Ne, and Ar isotopes).

EXTINCT RADIOACTIVITY (I^{129} - Xe^{129})

Measurement of the isotopic abundance of Xe^{129}, relative to the other Xe isotopes, may shed some light on the age of the moon relative to the age of the formation of elements in the solar system. The appearance of a Xe^{129} "anomaly" indicates that a rock (or mineral) cooled to a temperature below which Xe no longer escaped from the rock in a time short compared to several half-lives of its radioactive parent, I^{129} ($T_{1/2} \simeq 1.6 \times 10^7$ y). The time interval between the end of nucleosynthesis and that time of cooling can be calculated if the iodine content and "normal" xenon isotopic ratios are determined. That interval can then be compared to those obtained for the earth and meteorites.

NOBLE GAS CONTENT (PRIMORDIAL)

Analysis of the relative abundance of the noble gases (compared to silicon) enables us to determine something about physico-chemical conditions during the early history of the solar system. For example, it has been shown by Brown (Ref. 14) that terrestrial noble gases have been fractionated relative to solar or cosmic abundance, the degree of fractionation being mass dependent. The fact that certain volatile substances, e.g. H_2O and CO_2, have not been similarly fractionated indicates that those volatiles must have been held in chemical combination and that present terrestrial water has probably been progressively degassed from an initially cool earth.

STABLE ISOTOPE MEASUREMENTS

Analysis of the stable isotopes can shed light on the chemical, thermal and nuclear history of lunar material. As an example, it has been found by Taylor (Ref. 15) that the O^{18}/O^{16} ratio in silicate minerals is a function of the degree of magmatic differentiation which the particular rock has undergone.

Likewise, tektites seem to have a unique O^{18}/O^{16} ratio which falls in line with the magmatic differentiation trend. Thus the oxygen isotope analysis of lunar rocks and minerals may tell us about lunar magmatic differentiation and also about the possible lunar origin of tektites.

TRACE ELEMENT CONTENT

The relative and absolute abundances of the trace elements will give excellent indications of the chemical history of lunar material, since those abundances change according to the degree of magmatic differentiation, volatilization, oxygen pressure, etc., to which the elements have been exposed. Currently the distribution and abundance of the rare earth elements (Ref. 16) in terrestrial and meteoritic rocks and minerals is being actively studied and is allowing new interpretation of earth and meteorite evolution. A similar study on lunar material would provide data for the comparison of physico-chemical processes in the three distinctive bodies.

The determination of the content of radioactive elements e.g. K^{40}, U, and Th, will, among other things, enable construction of much better lunar thermal models than is presently possible.

GROSS CHEMICAL COMPOSITION

Determination of the gross chemistry will enable the same general type of interpretations to be made concerning lunar evolution as will trace element analyses, i.e. has magmatic differentiation occurred, is lunar material similar to terrestrial or meteoritic material, and are geological processes different on the moon from those on earth?

SEARCH FOR SHOCK EFFECTS

The shock effects which have been observed in some terrestrial meteorite impact craters include extreme brecciation of the country rock, formation of shatter cones, and formation of high pressure polymorphs of silica. It has also been hypothesized (Ref. 17) that diamonds in certain meteorites were created by shock pressures generated upon impact. Observation of the presence or lack of the shock effects would, eventually, build up evidence bearing on the problem of impact vs. volcanic origin of lunar craters.

MINERALOGY

The specific mineralogy of any rock is perhaps the best single clue as to the origin of the rock, especially in the absence of sufficient field data which might be diagnostic in itself. Sometimes a single mineral may be indicative but more often it is the mineral assemblage which is important, for the assemblage will be unique for a given bulk chemistry and equilibrium physico-chemical conditions. The interpretation of the analysis will be based upon a broad background of interpreting terrestrial rocks and also on a multitude of laboratory syntheses.

The mineralogical analyses will be carried out by a combination of x-ray, optical, and chemical methods, the first two being non-destructive, repeatable and using small samples.

PETROGRAPHY

Petrographic study of rock specimens adds immensely to the over-all interpretation of the geologic history of the sample. Among other things, such a study is concerned with the determination of crystallinity, mineral grain size, mutual relationships (order of crystallization), preferred orientations, alterations, and relative mineral abundances. Petrography is usually done microscopically although on occasion, if crystal size is large, examination of hand specimens is needed. That factor is one which must be evaluated by the astronaut engaged in sample collection.

PHYSICAL MEASUREMENTS

Included in this type of measurement would be the thermal conductivity, sonic velocity, and magnetic properties. The thermal properties need to be known in order to interpret lunar hear flow and to allow better interpretation of the thermal inertia term $(k\rho c)^{-1/2}$ obtained from studies of lunar electromagnetic radiation. Knowledge of sonic velocity aids in the analysis of seismic experiments while analysis of certain magnetic properties may shed light on the question of whether or not the moon has had a magnetic field and if so, how strong it was and how it was oriented. It is essential that complete lunar orientation of the sample be known if the magnetic measurements are to be used to full advantage. In all probability the orientation will have to be done relative to local topographic features and to the LEM.

4.5 Emplacement of Equipment Requiring Human Dexterity or Decision-Making Capability:

Most of the experiments carried out using instruments fall in the category of solid body geophysics and include seismology, magnetic measurements, gravity measurements, rock radioactivity measurements, and thermal measurements.

SEISMOLOGY

Determination and analysis of seismic activity on the moon would have great implications concerning the thermal structure, layering,and strength of that body. One seismological station would be acceptable as a start but establishment of a seismological network of at least three stations is preferable. (Ref. 18). Knowledge of epicenter location allows one to make better models of the internal structure of the moon than would simply knowing that seismic activity exists.

The role of the astronaut would be to emplace the seismograph unit on a suitable base and to determine its location. It is unlikely that more than one station could be established per flight for two reasons: the astronauts will have limited mobility and range, thus could not establish a wide-base network, and the instrument package is apt to be heavy, allowing only one per payload. In order to use seismometer stations in a network, then, certain requirements have to be met.

(a) Each flight must carry a seismometer unit (at least until a net is established).

(b) Landing sites must be picked with optimum base lines in mind.

(c) Seismometer stations must be capable of operating for a long time (years?) since a large time interval may elapse between emplacement of the first and third operating instruments or the stations must be able to lie dormant until commanded to start operation. This implies that the lunar environment is conducive to long-term operation.

It is possible that it may not be feasible to establish a seismological net by the one station per flight method, but that it would be more sensible to concentrate on supplying motive capability to the astronauts and thus allow establishment of a net during one "seismological" flight. This is an area deserving of further study.

In addition to the moonquake seismology there may be use for local refraction seismometry utilizing man-made explosions or other energy sources, particularly with respect to determining the depth of "dust" or breccia layers. Other layering (e.g. lava flows) may also be discernable, but this is apt to demand wide baselines (thus mobility) and be time consuming, depending on the depth of layering.

MAGNETIC MEASUREMENTS

The Sonett report (Ref. 6) recommends that astronauts not make extensive magnetic field surveys for geological purposes. In view of the multitude of individual measurements needed, thus high mobility and range, and probably complexity of the situation due to iron or stoney-iron meteorite debris, I concur with that recommendation. However, this does not negate the desirability of making at least a spot check of the magnetism in the landing area. At present, all that we know is that the lunar magnetic field at $\sim$1 km height is probably less than 60 gamma and that the surface field should be less than several hundred to a thousand gamma. (Ref.19).

GRAVITY MEASUREMENTS

Extensive gravity surveys are not recommended for the same reasons as magnetic and additionally on account of the necessity for having good topographic maps and knowledge of rock densities. This type of survey, however, along with magnetic, should be considered under lunar base studies since it might be important in distinguishing impact from volcanic craters, hidden structure, degree of isostatic adjustment, etc.

Van Atta (Ref. 7) has presented a case for conducting long term ($\sim$ 1 year) gravity monitoring at one lunar station in order to gain information concerning lunar body tides which in turn enable analysis of the internal structure of the moon. Van Atta claims that there is no apparent necessity for having an astronaut conduct or set up this experiment -- it could probably be done by an unmanned flight.

In the limit that may be so yet it may well be that a better experiment could be performed, at less cost, utilizing power and telemetry equipment which may be carried by Apollo irregardless of the gravity experiment.

ROCK RADIOACTIVITY MEASUREMENTS

It has been suggested in the Sonett report (Ref. 6) that local rock radioactivity be measured in a drill hole (drilled for other purposes) and that a scintillometer be available for reconnaissance measurement of radioactivity, the hope being that the measurements would

(a) indicate whether or not radioactivity is an important source of heat near the surface, and

(b) enable the astronaut to get an idea as to the composition of "fine-grained indeterminate looking" surface material since we know that "granitic" rocks are more radioactive than "basaltic" rocks.

Point (a) is of questionable merit -- if the astronauts are able to drill a hole in the first place, they will certainly obtain samples of the drilled material for earth return where the radioactivity can be determined much better. Point (b) is valid and can be reinforced. If the lunar surface is covered with a thin homogeneous coating[see 4.40 (g)], the astronaut would not be able to distinguish different subsurface rock types. If he were monitoring surface radioactivity, however, he might find a subsurface change of rock type on account of a corresponding change in radioactivity. It is also conceivable that some unsuspected radioactivity will be found.

THERMAL MEASUREMENTS

Knowledge of the present day lunar heat flux will enable more accurate interpretation of the thermal history, radioactive chemical composition, and internal structure of the moon than is presently possible. It has been proposed (Ref. 2) that the temperature gradient and conductivity be measured in situ in a drill hole (if a probe cannot be easily inserted in relatively loose material) of the order of 5-20 feet deep. Since it might not be possible to obtain equilibrium conditions in a short time(comparable to stay time),thus necessitating

power and telemetry equipment, this experiment may have to wait until payload is increased (this holds also for other experiments needing long-term power and telemetry - e.g. seismic and gravity).

4.6 Astrophysical Experiments Using the Moon as a Stable Space Platform

Of the proposed astrophysical experiments, the one concerned with determining the precise direction of rotation of the moon and the amplitude of lunar physical librations must be done by an observer on the lunar surface if the desired accuracy is to be obtained (Ref. 6). As stated, the measurement would consist of locating "a solid instrument site away from the spacecraft," setting up the instrument and making the theodolite observations of several star positions at intervals over a period of 2-4 days. The ultimate aim is to obtain better knowledge of the lunar moments of inertia, thus enabling better calculation to be made of lunar mass distribution.

The remainder of the proposed astrophysical experiments involve using the moon as a stable platform for making astrophysical observations on extralunar objects. Included (Ref. 7) are long-wave radio astronomy, radio astronomy, radio interferometry, optical interferometry, ultraviolet spectroscopy, etc. Arguments have been advanced both in support of and against using the moon as a stable platform (Refs. 6, 7, 20) usually in relationship to the alternative of an Orbiting Astronomical Observatory. On the credit side, as given by Pearse (Ref.20):

(1)* Because the moon is known to have a negligible magnetic field, the interpretation of data relating to primary cosmic rays, solar flare protons and solar wind protons is greatly simplified. A lunar based, long-lived observation station would be very desirable for studying those phenomena.

(2)* The use of the moon as an observational platform would be desirable because the negligible lunar atmosphere results in good astronomical "seeing" over virtually the entire electromagnetic spectrum.

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* It is recognized that orbiting spacecraft have similar environments, however, they have serious long term disadvantages, such as limited lifetimes, due to depletion of gas needed to achieve pointing, etc.

The making of astrophysical observations during the lunar night offers two distinct advantages over an Orbiting Astronomical Observatory:

(a) Since the lunar night temperature is nearly constant, due to the absence of solar heating, differential heating problems in telescope design are eliminated.

(b) Due to the absence of solar light, problems with light scattering into the telescope are minimized.

(3) Because the moon is a spin-stabilized, approximately earth-oriented satellite, telescope and telemetry antenna pointing problems are minimized. In conjunction with these, it should be noted that a view of half the earth is obtained.

On the debit side (Ref. 7):

(1) A heavier telescope structure would be needed on the moon to control flexure.

(2) Effects of day-night large temperature variations would be hard to control.

(3) Large cost.

(4) Lunar dust may be a problem.

Certain astronomical experiments, such as those requiring shielding from the earth, cannot be done easily with a satellite. However, those experiments require operation on the lunar back-side, a modus operandi which early Apollo flights will probably not allow.

Success of one or more OAO's prior to Apollo landings would undoubtedly reduce the demand for certain lunar based experiments. Yet, if terrestrial analogy is valid, there will be other experiments suggested which will involve using the moon as a stable platform. In anticipation of this, and since no clear-cut decision can be made except in a rather arbitrary manner, the early Apollo program should be concerned with determining whether or not the moon could be used as a stable platform. Most of the factors involved in the decision will be environmental and will be determined as part of the overall

lunar exploration program, e.g., radiation and solid particle flux. Studies should be conducted, however, to determine specifically what type of information would be needed to certify a lunar astronomical observation site.

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